Iterative Mean-field Approach to dark matter halo structure

- find the universality in the complex

Xun Shi 石洵

South-Western Institute for Astronomy Research

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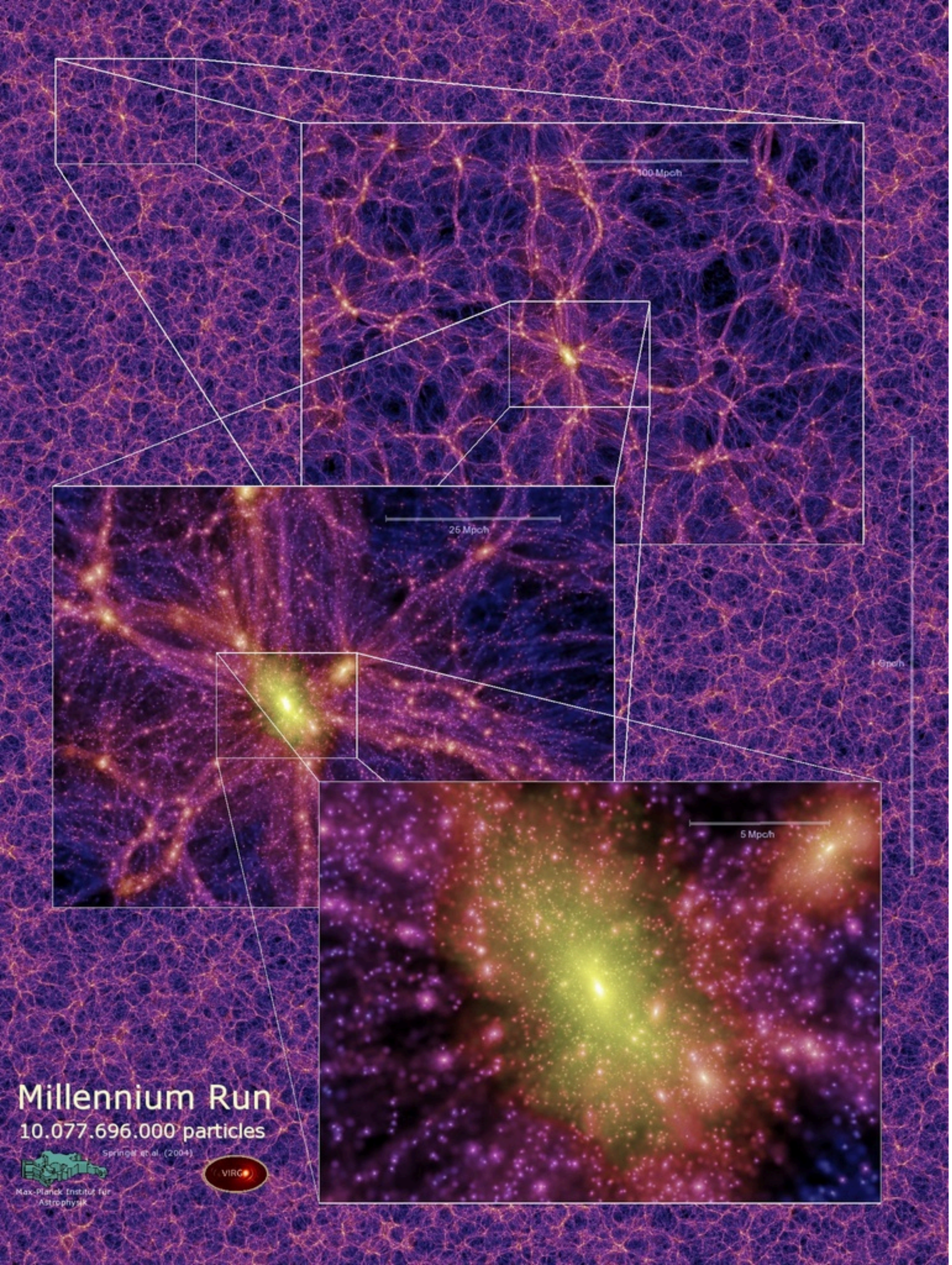


The spherically averaged density profiles of all our halos can be fit over two decades in radius by scaling ***a simple 'universal' profile****… Halo profiles are approximately isothermal over a large range in radii, but are significantly shallower than* r^{-2} *near the center and steeper than* r^{-2} *near the virial radius*

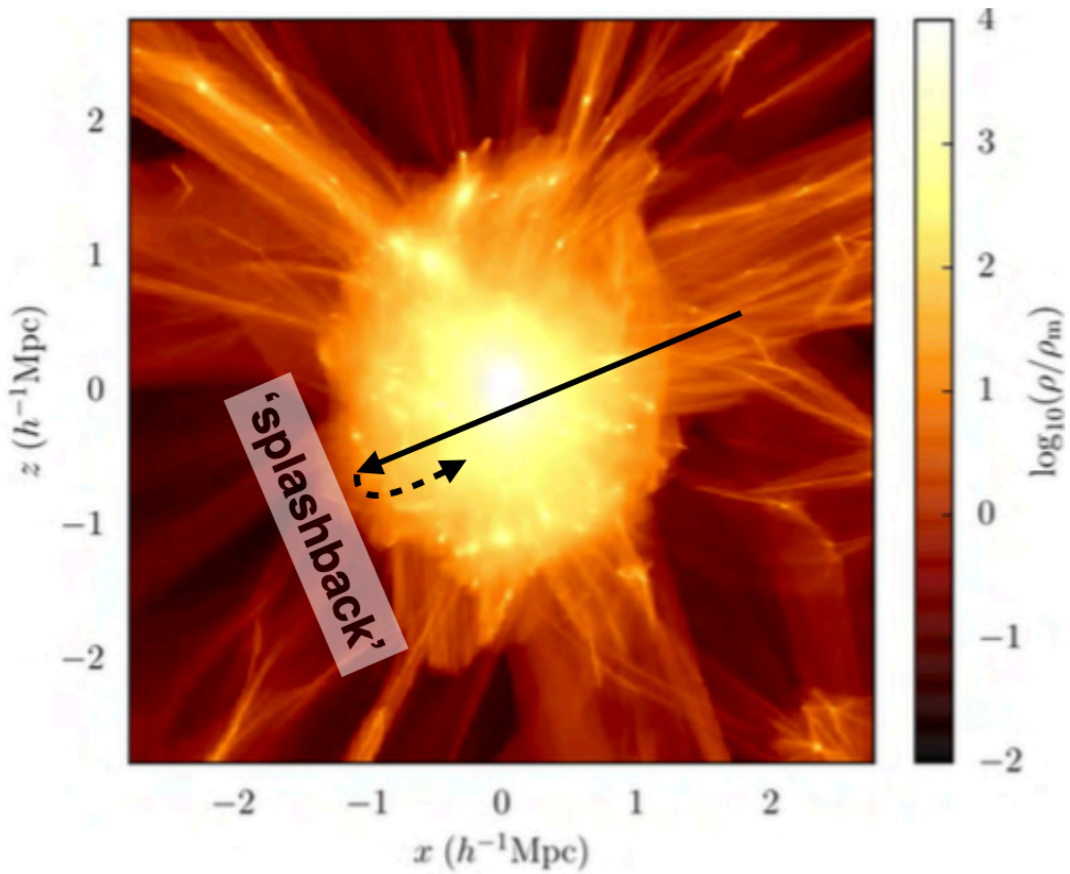
Navarro, Frenk & White 1996, 1997

Detailed shapes: Jing+00, Meritt+05, 06, Wang+20…

Non-CDM models: Ishiyama+10, Angulo+17, Delos & White22…

Observations: Okabe+13, Wang+16…

Outside the Virial radius



Diemer & Kravtsov 14

density reconstructed using phase space sheet, cf. Hahn & Abel 11

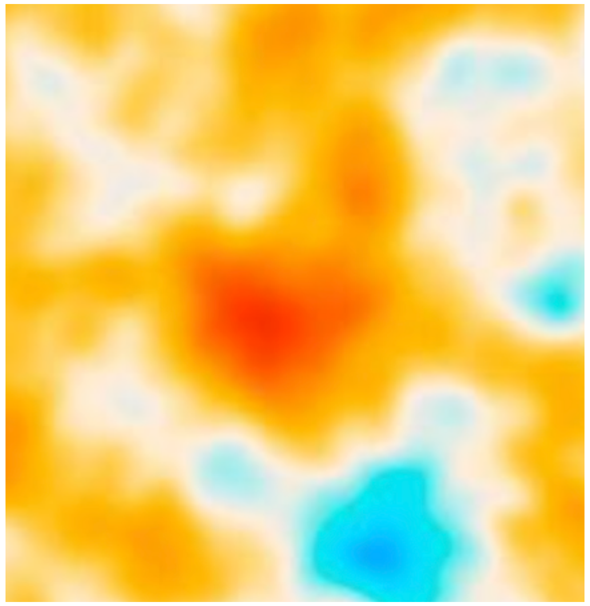
Splashback: sharp edge in DM density profile outside R_{vir} (Diemer&Kravtsov14, Adhikari+14…)

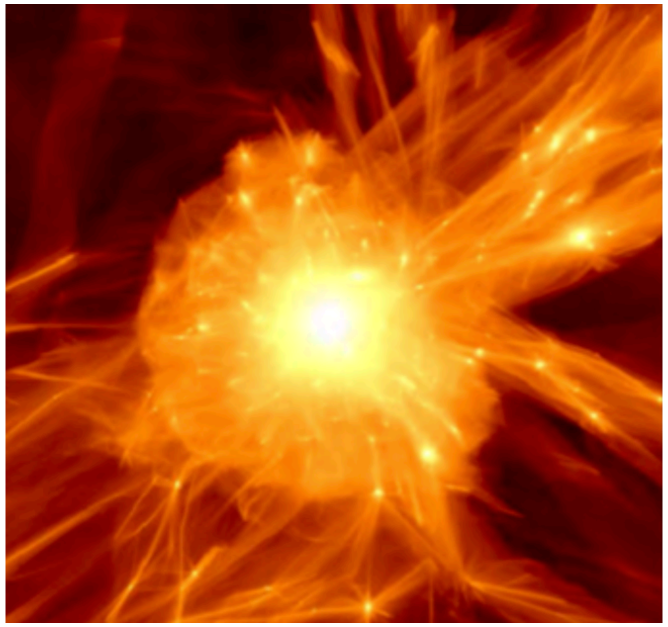
Depletion region: low-density region depleted by halo growth (Fong&Han21…)

To understand the DM halo structure is to

understand the mapping:

initial overdensity peak → *(late time) dark matter halo*





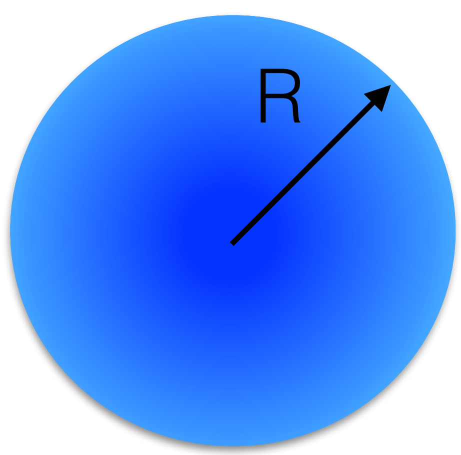
Spherical collapse models FOR **Outer structure of DM halos**

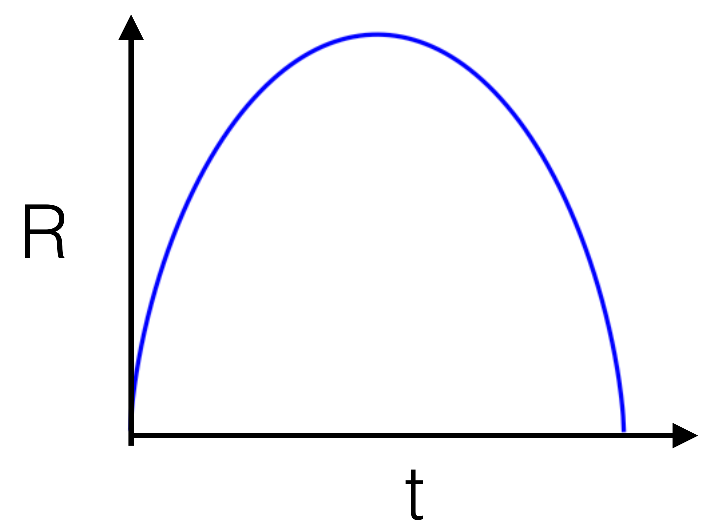
Pro: *treat* ***single-/few-stream regime*** *well*	*need careful modeling of* ***NFW-single stream transition***
Con: *miss some physics that shape the* ***inner parts*** *of halos*	***not much influenced by inner parts*** *of halos*

A good match !

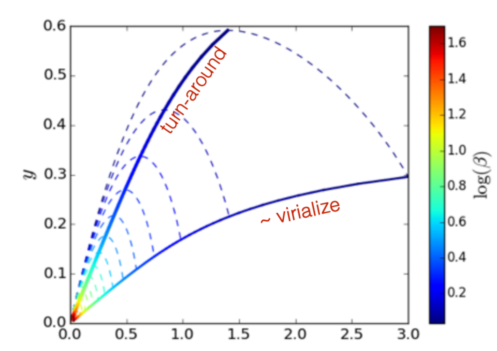
Spherical collapse model++

- *Spherical collapse (Gunn & Gott 72)* *for a single DM shell, single stream*
  + adiabatic invariant (Gunn 77 and many others) *approximate multi-stream*

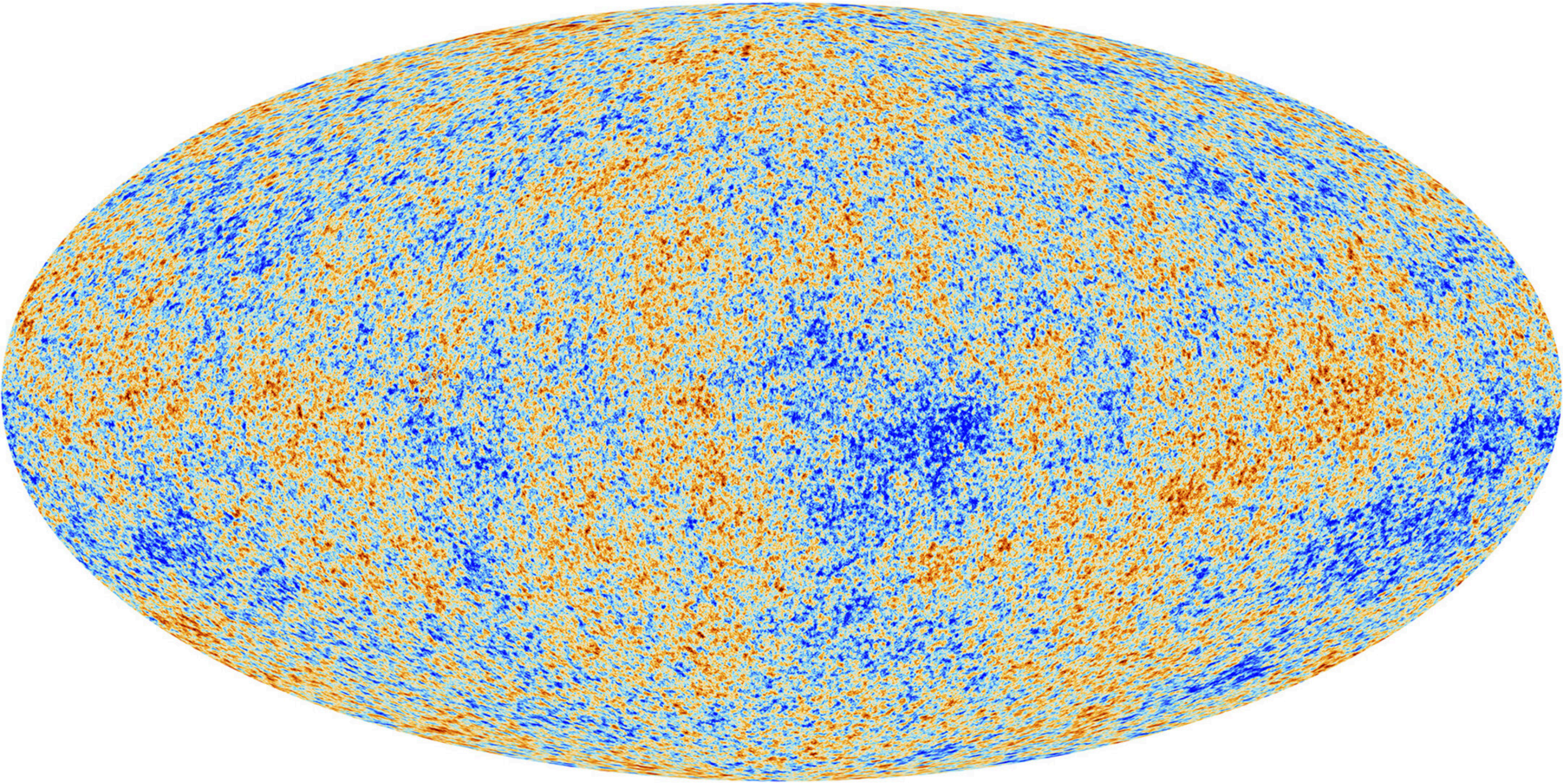




**single-parameter spherical collapse in LCDM: β combines M, δ and $\Omega_{\rm m}$*



appendix of Shi16

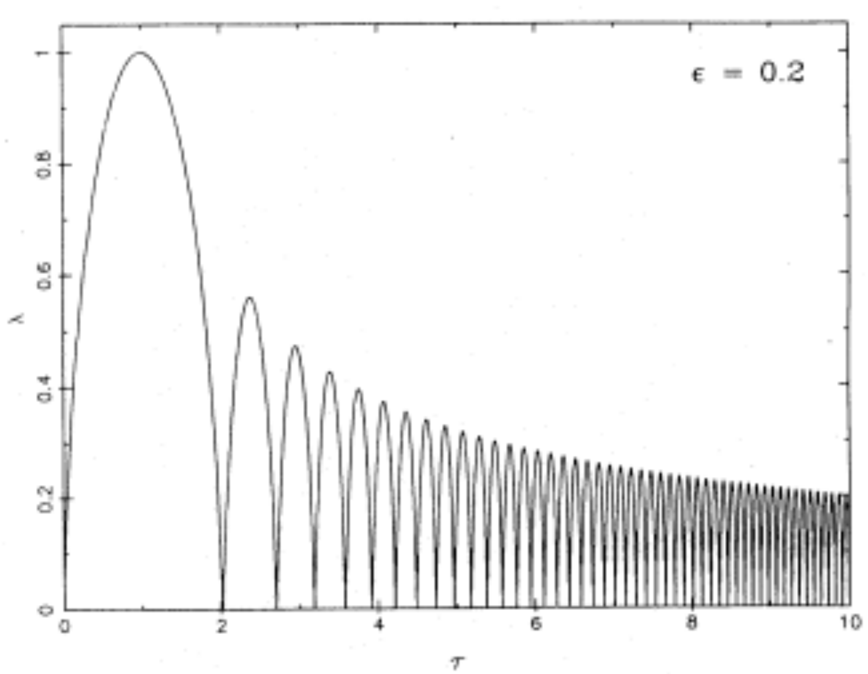


initial condition —*Spherical collapse*→ *when & where halos of what mass will form*

Spherical collapse model++

- *Spherical collapse (Gunn & Gott 72) for a single DM shell, single stream*
  + adiabatic invariant (Gunn 77 and many others) approximate multi-stream

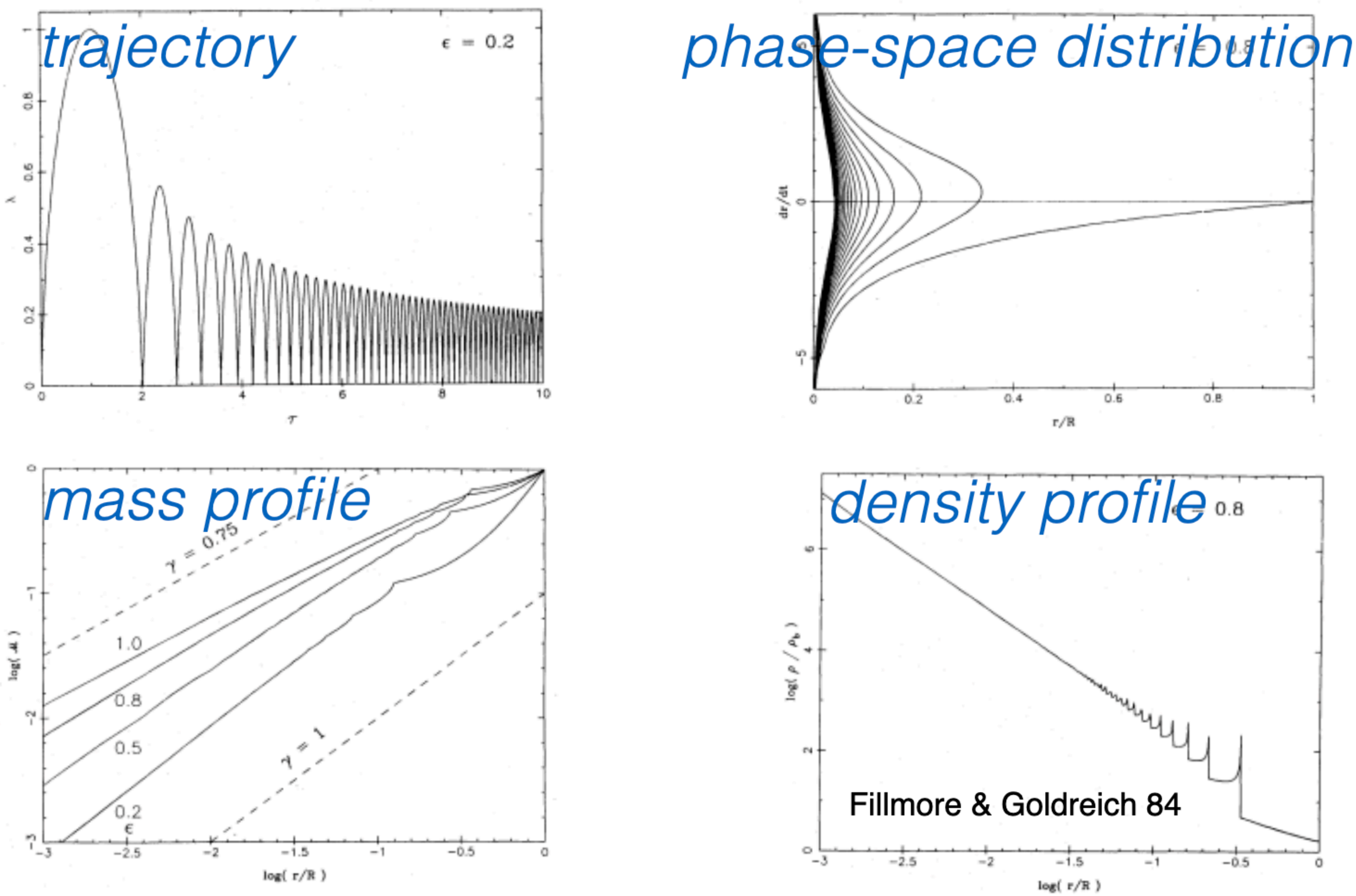
- *Self-similar spherical collapse (Fillmore & Goldreich 84, Bertschinger 85, Lithwick & Dalal 11)*
  ***density profile** for single- & **multi-stream** region! but EdS, power-law MAH*



the power of self-similarity:
trajectory of 1 shell ~ positions of all shells in 1 snapshot

Fine-grained structure of DM halos

as revealed by self-similar spherical collapse



Not just a special case! ***Self-similar solutions are intermediate asymptotics (~attractor)*** *of the dynamics (Zel'dovich, Raizer, Barenblatt)*

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How to find the attractor under non-restrictive conditions??

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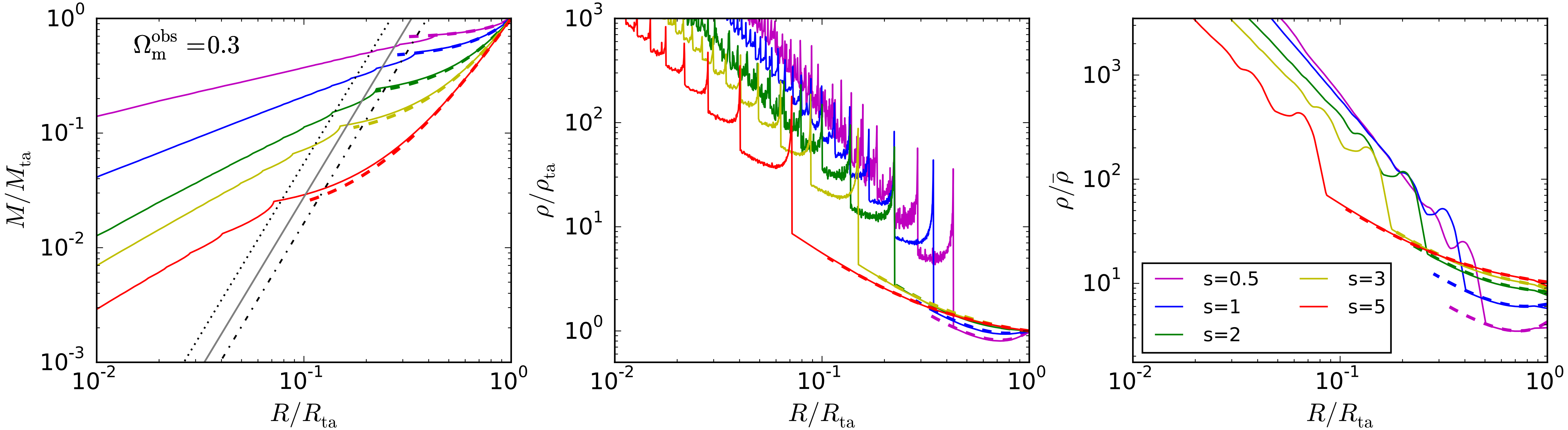
to find the attractor under non-restrictive conditions:

- *Near self-similar spherical collapse (Shi 16)*
  *perturb around self-similar solution; **LCDM**, but power-law MAH*

Mass and density profiles in a ΛCDM universe

for a certain Ω_m and accretion rate s

consider power law mass growth $M \propto a^s$



3 regimes:

power-law inner profile;

density drop at splashback radius;

accretion region (before shell-crossing)

higher accretion rate, smaller R_{sp} / R_{ta}

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to find the attractor under non-restrictive conditions:

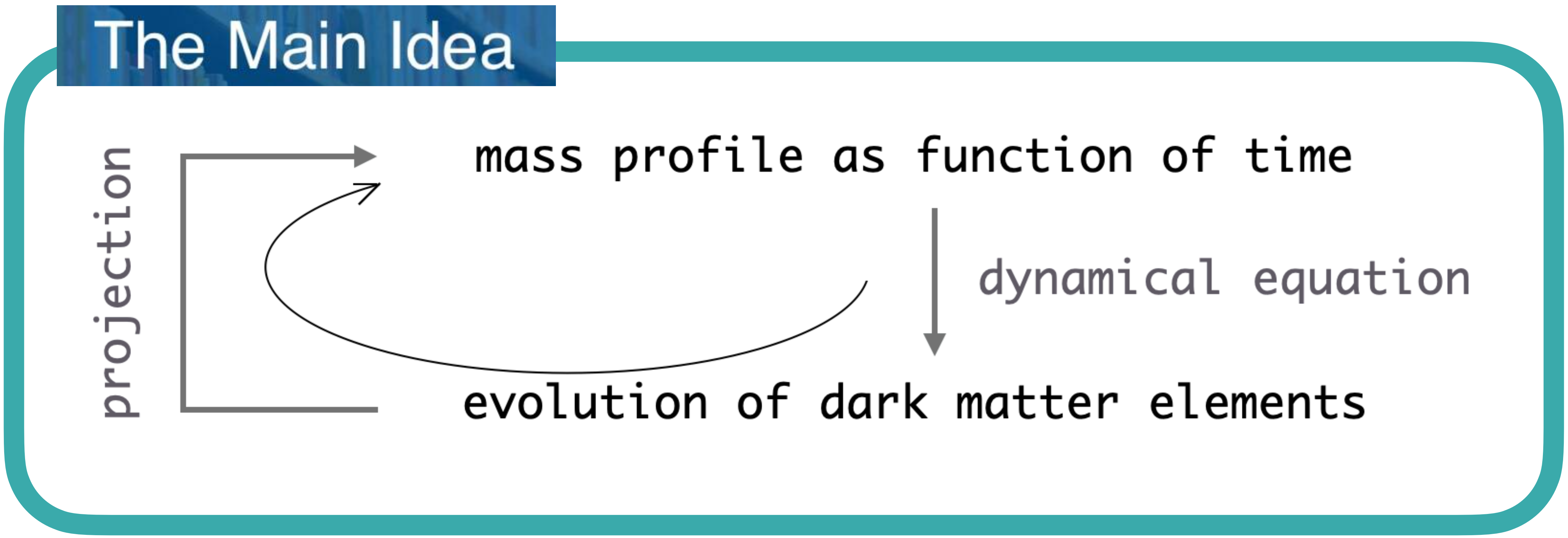
- *Near self-similar spherical collapse (Shi 16)*
  *perturb around self-similar solution; **LCDM**, but power-law MAH*

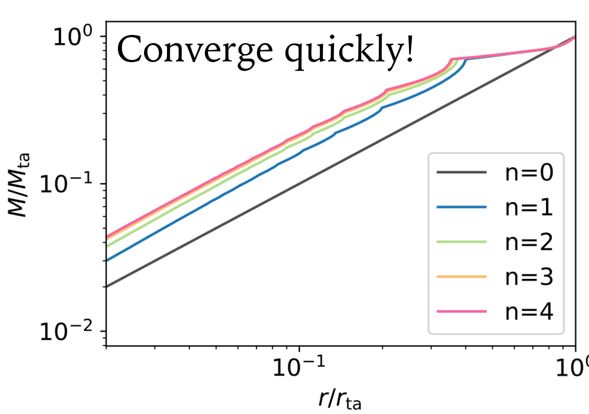
- *Iterative mean-field approach to spherical collapse (Shi 23)*
  *self-similar solution → **intermediate attractor; LCDM, realistic MAH!***

enable direct comparison to simulations

Iterative mean-field approach to spherical collapse

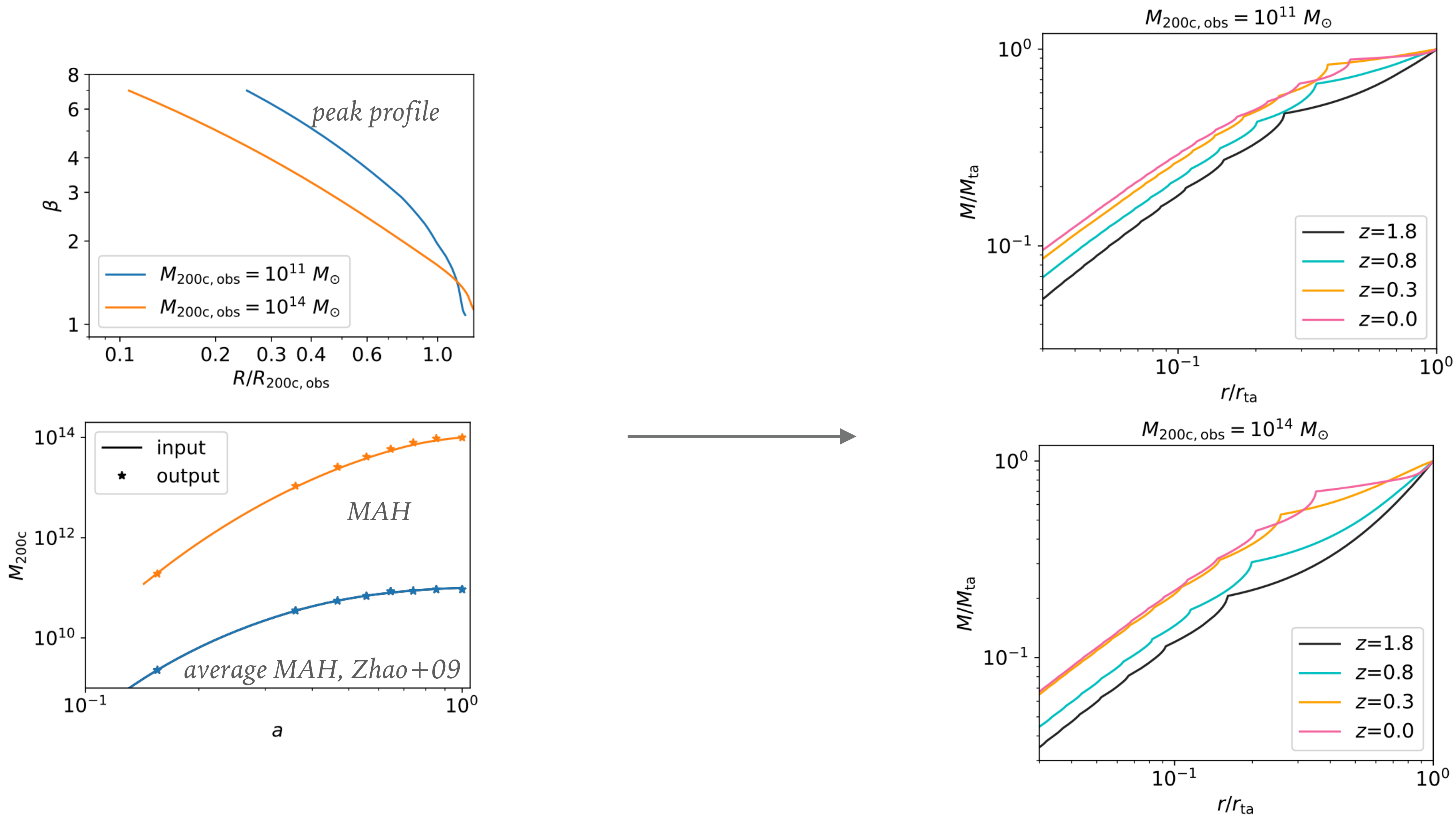
Method: mass profile - trajectory iteration



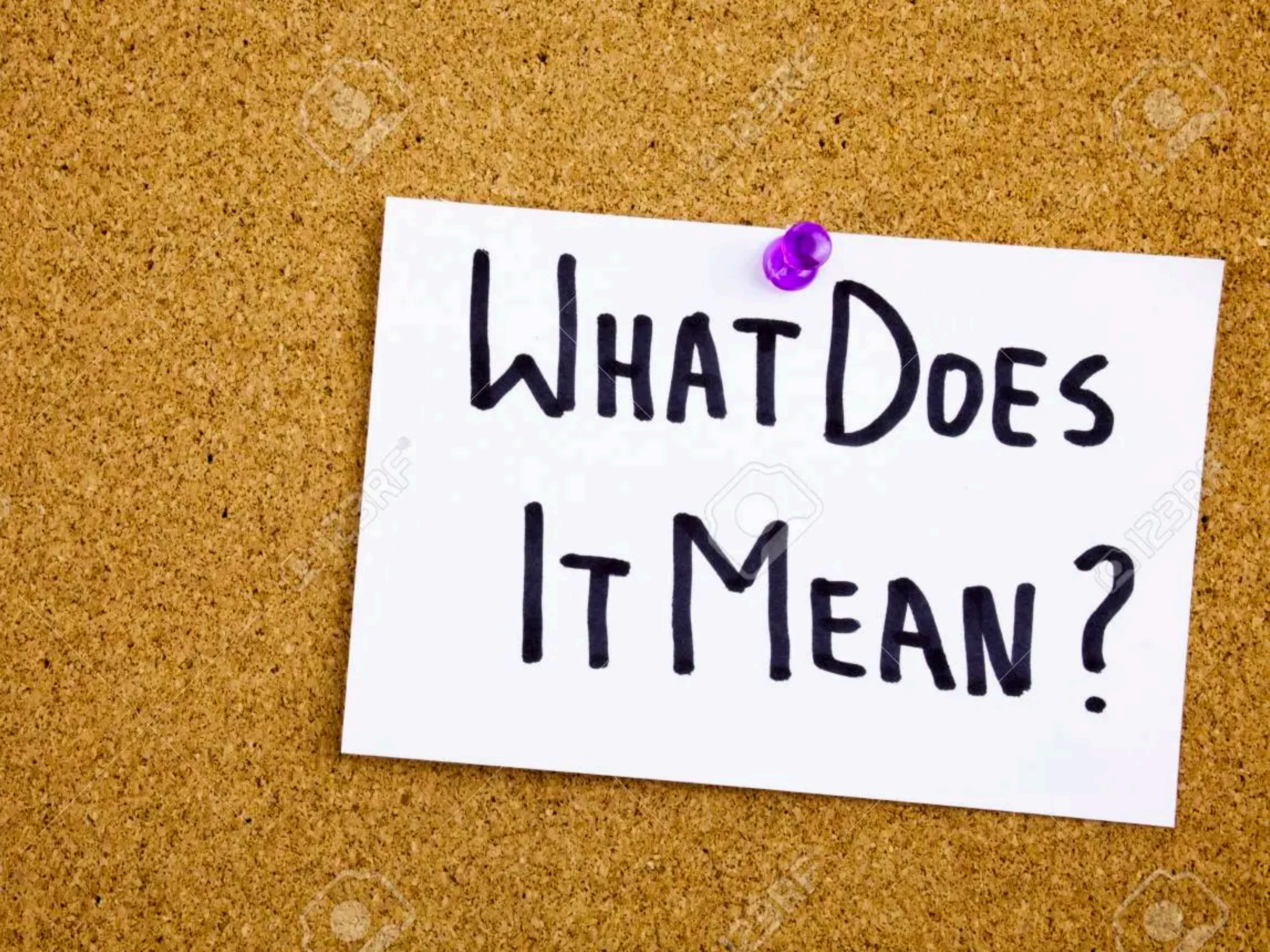


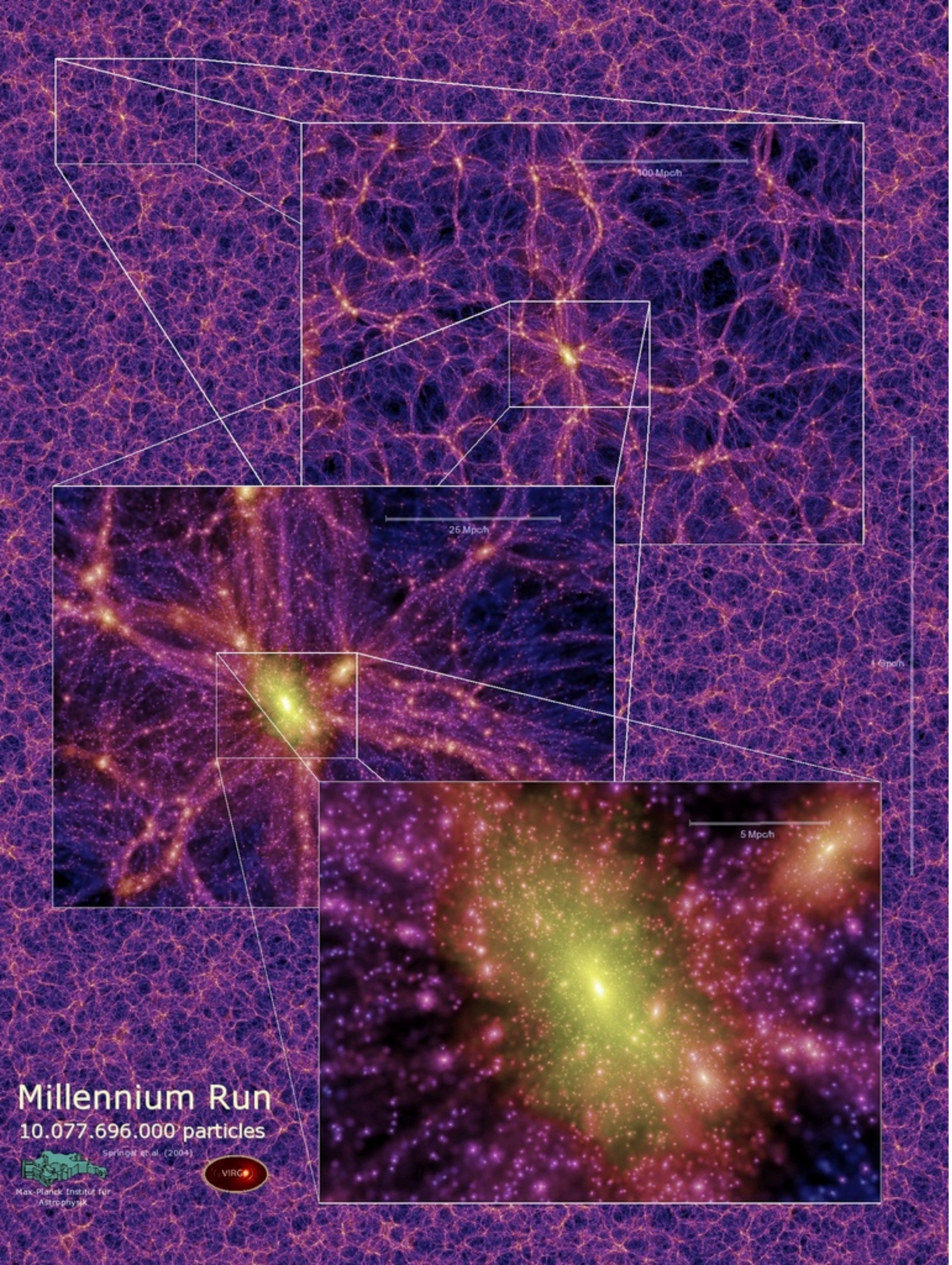
Iterative mean-field approach to spherical collapse

outer structure of DM halos for realistic MAH in LCDM universe



Now: Compare to simulation results with your peak profile / MAH? Explore parameter dependence?


WHAT DOES
IT MEAN?



NFW-like density profile is an attractor

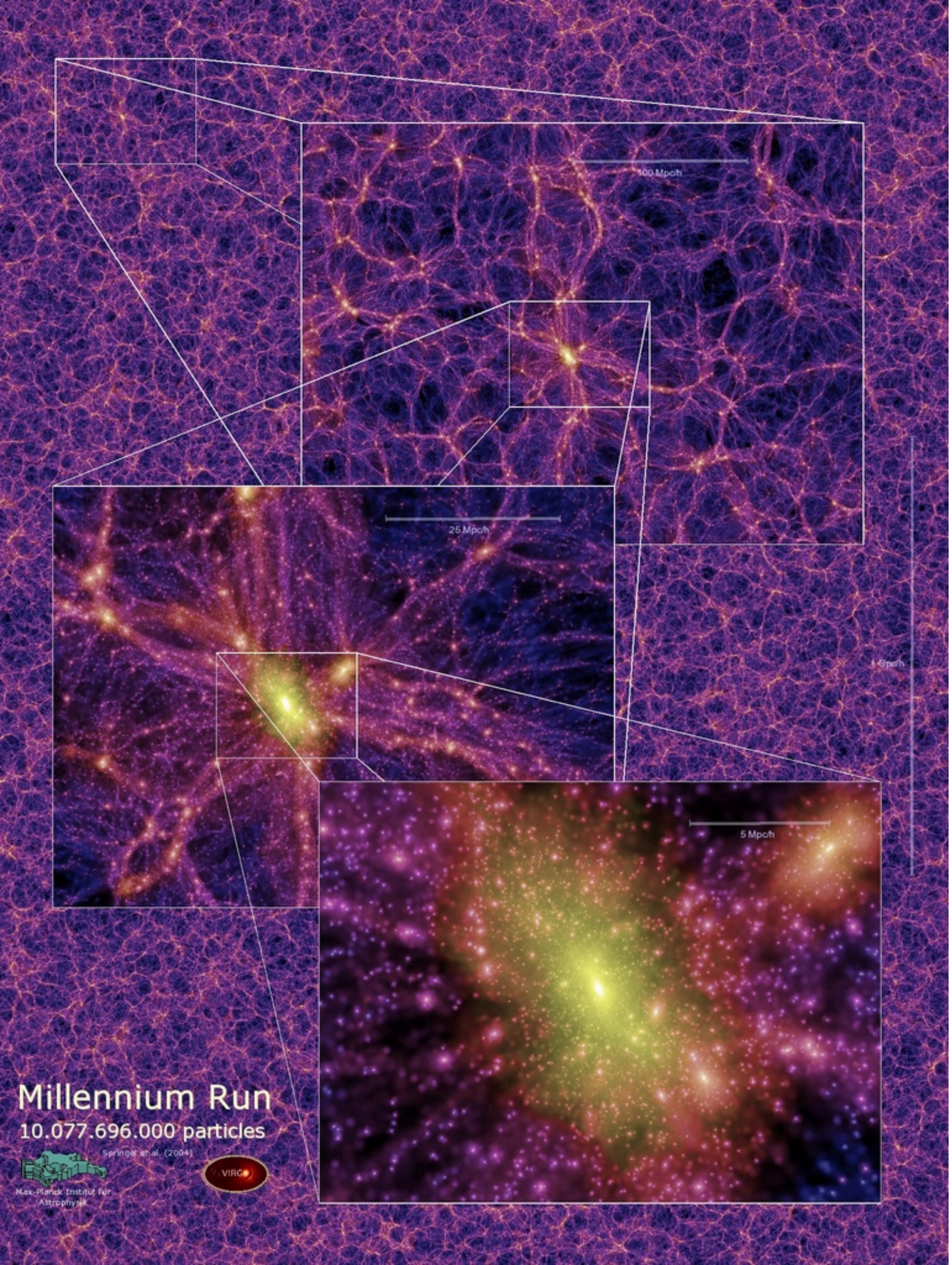
to non-linear grav. dynamics (Ishiyama14; Angulo+17; Ogiya & Hahn 18; Delos&White 22)

many efforts to ***understand its emergence***

(e.g. Ascasibar+04; Lu+06; Dalal+10; Hjorth&Williams+10; Ludlow+13; Pontzen&Governato13; Williams&Hjorth22)

For us: +triaxiality +angular momentum

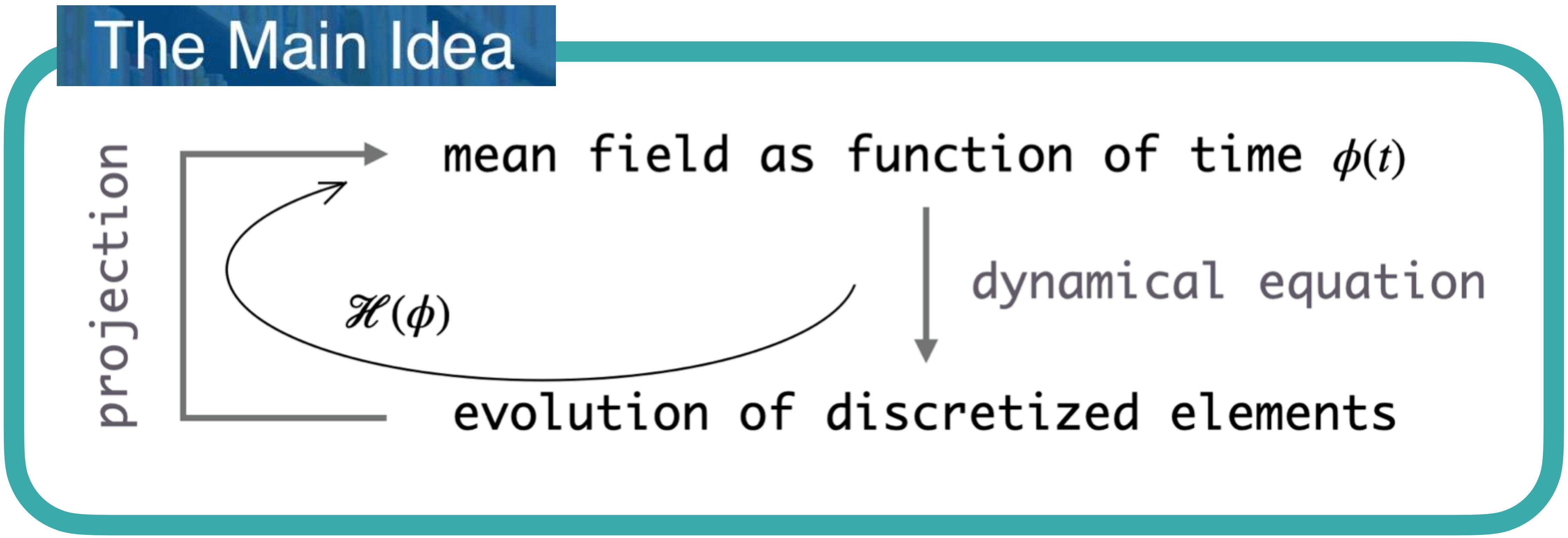
like Lithwick&Dalal11 for self-similar spherical collapse

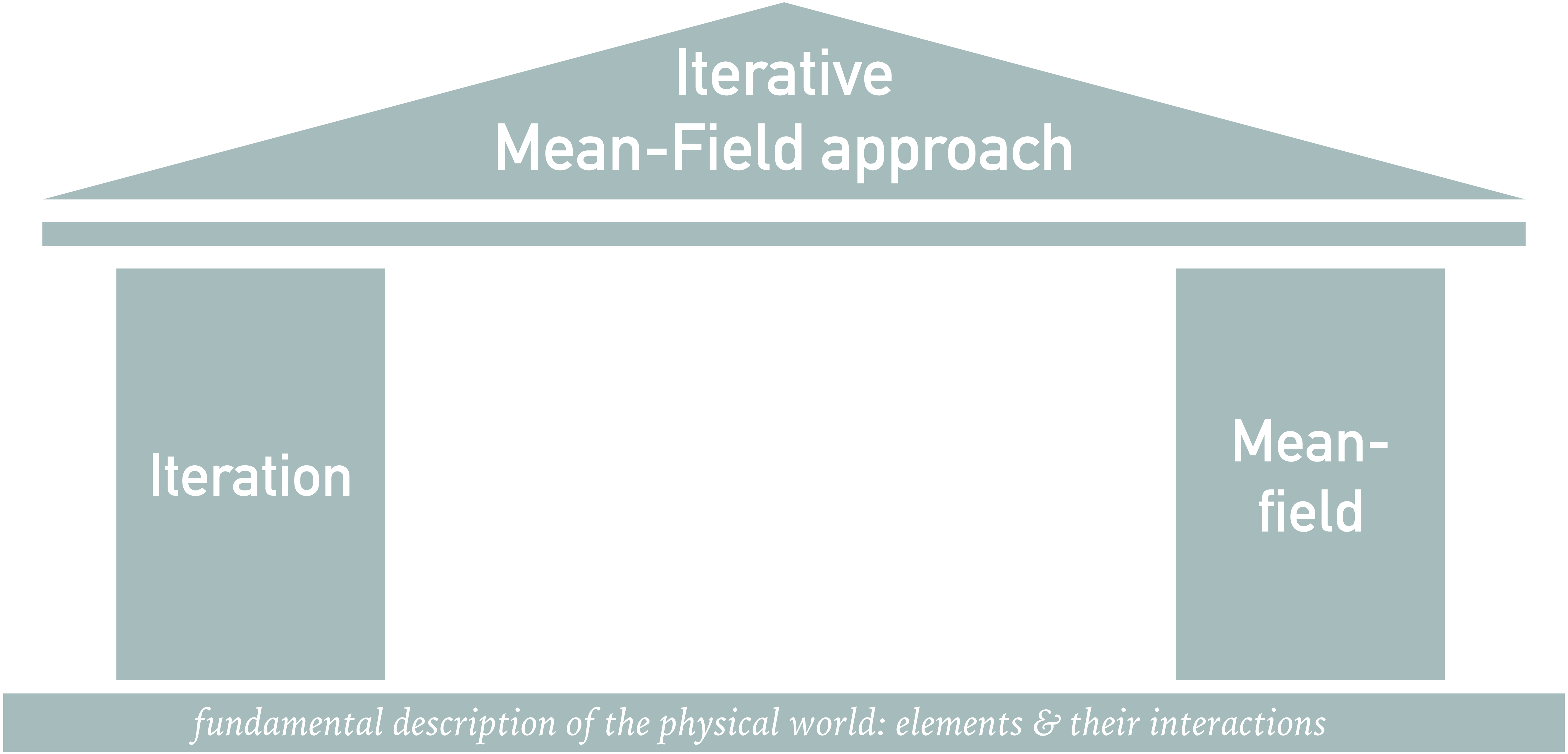


Universal profile of DM halos is a poster-child example of ***self-organized emergent universality*** *in a complex system*

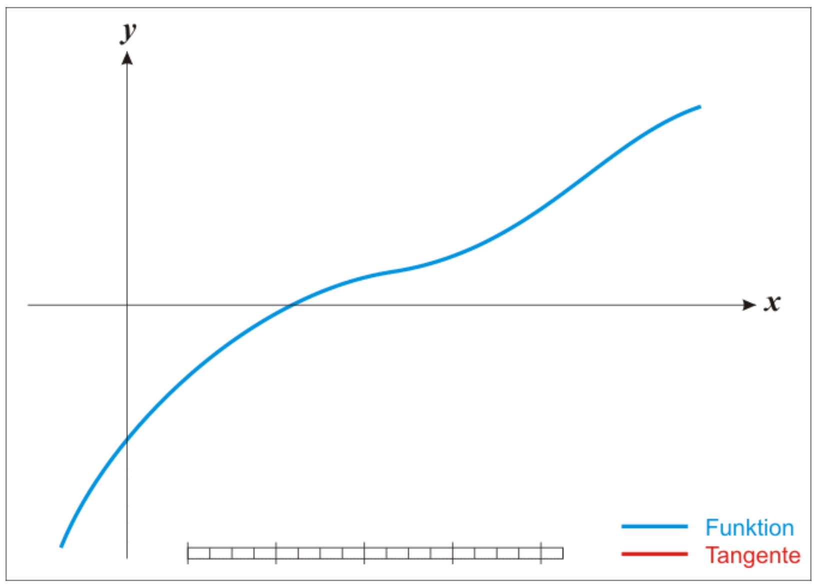
- *microscopic interaction* ✔
- *initial condition* ✔

Iterative Mean-Field approach to a general dynamical system

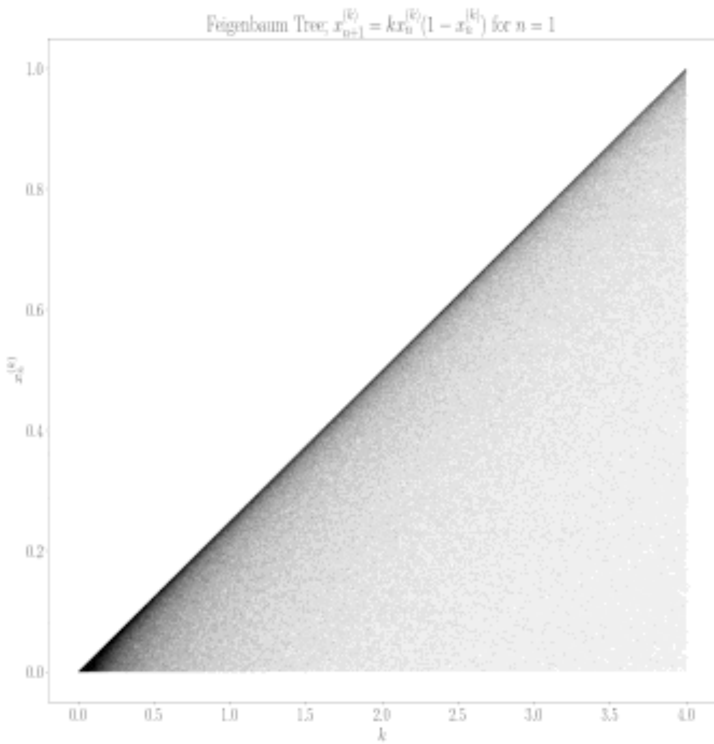



Iterative
Mean-Field approach
Iteration
Mean-
field
fundamental description of the physical world: elements & their interactions

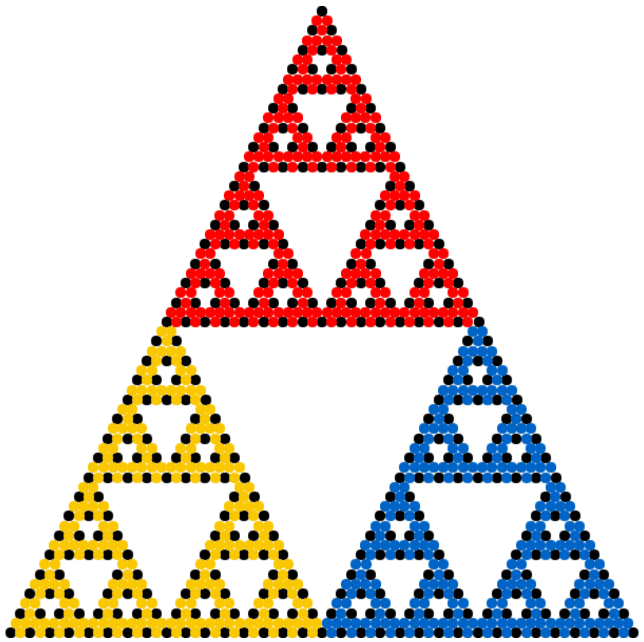
The Power of Iterations



[Newton–Raphson method]



[logistic map]

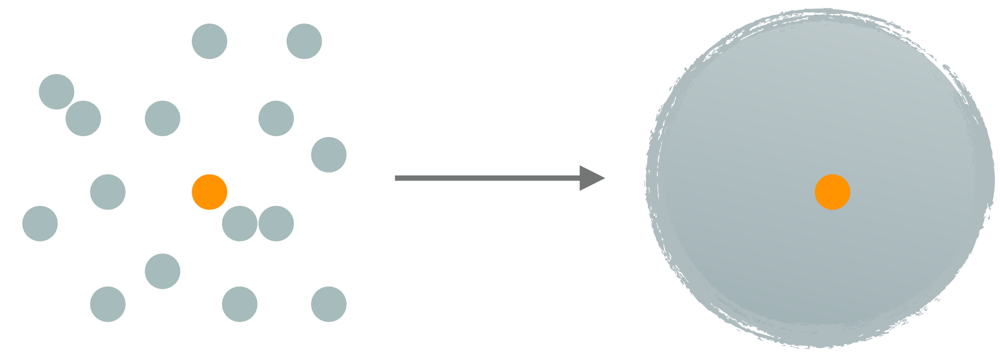


[Sierpinski Chaos]

Iterative Mean-Field: ***iteration in the functional space***

The Power of Mean-field

- *many-body problem → one-body problem*

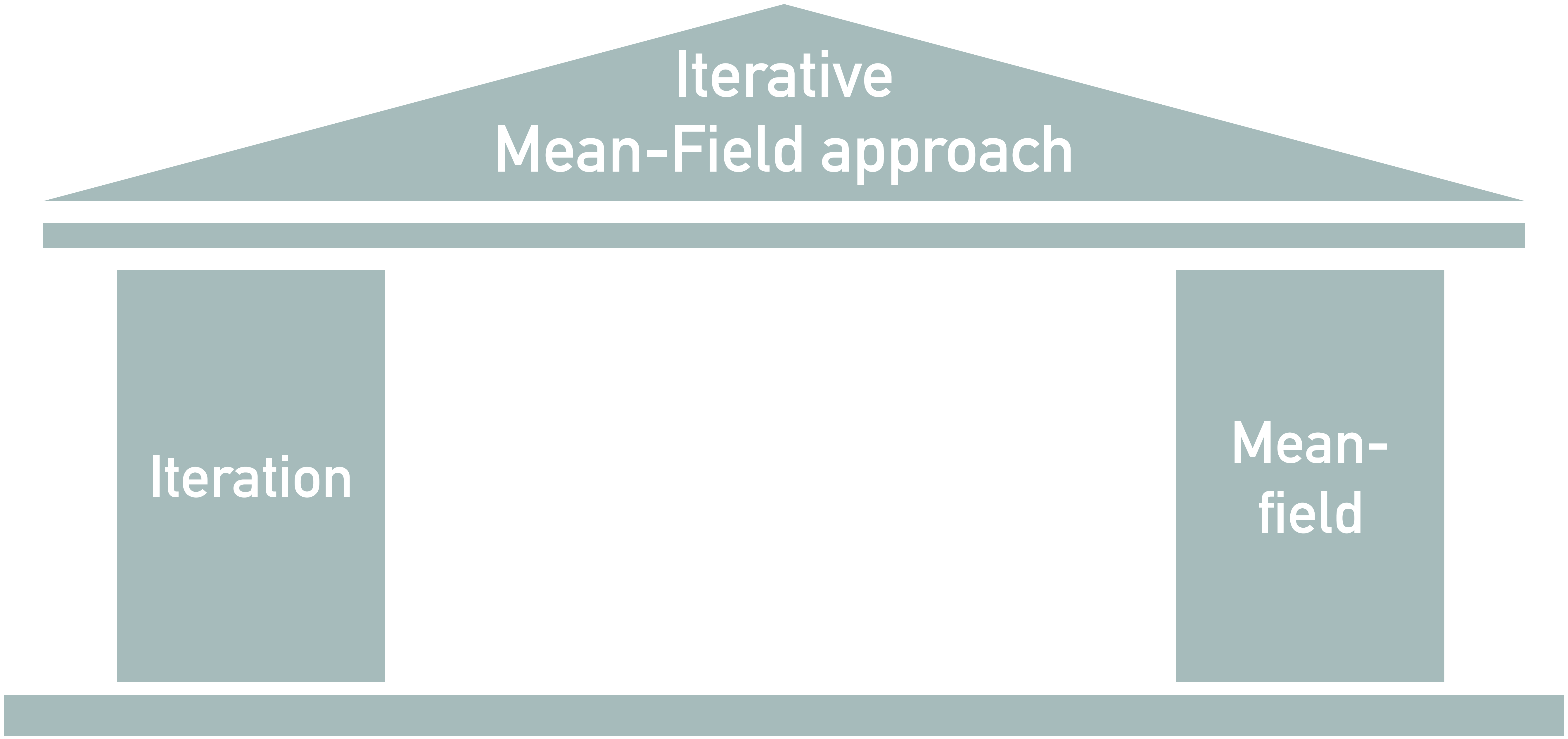


- *insight at a lower computational cost*

- *broad applications: physics, probability theory, statistical inference, graphical models, neuroscience, artificial intelligence, epidemic models, queueing theory, computer-network performance, game theory…*

《相变和临界现象》插图

Iterative Mean-Field: ***look for a consistent, dynamic mean-field***


Iterative
Mean-Field approach
Iteration
Mean-
field

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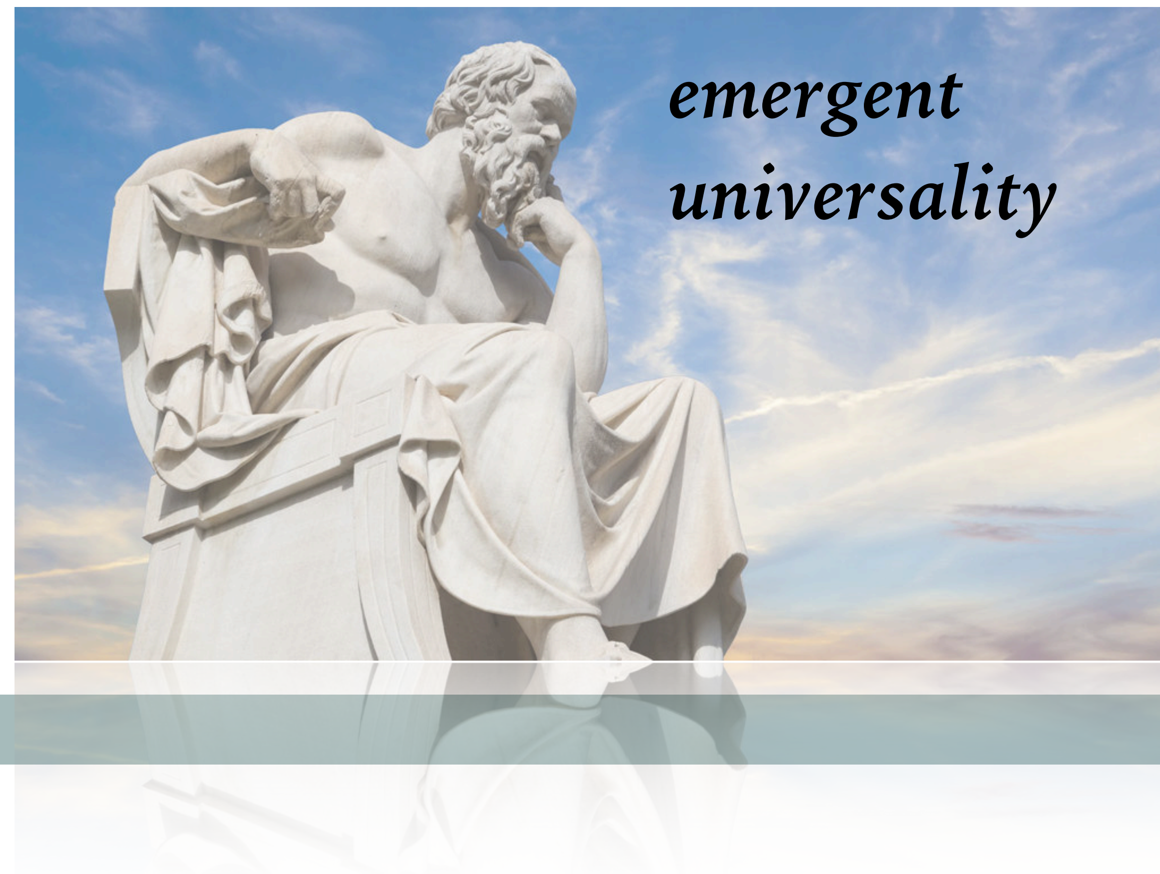
Iteration



Mean-
field

Self-similar solutions are emergent universality under restrictive conditions
- intermediate asymptotics of the dynamics(Zel'dovich, Raizer, Barenblatt)
- fixed points of renormalization-group transformation (Goldenfeld, Oono, Chen)

Iterative Mean-field approach can find emergent universality in dynamical systems for non-restrictive conditions